



UNIVERSITI PUTRA MALAYSIA

**DESIGN OF SINGLE SWITCH RECTIFIER FOR ELECTRIC
VEHICLE BATTERY CHARGER APPLICATION**

I N D R A N I S J A

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**DESIGN OF SINGLE SWITCH RECTIFIER FOR ELECTRIC VEHICLE
BATTERY CHARGER APPLICATION**

By

INDRA NISJA

**Thesis Submitted to the School of Graduate Studies Universiti Putra Malaysia
in Fulfillment of the Requirements for the Degree of Master of Science**

February 2002



Dedicated to:

***My Parents, My Wife Ellyza bt Zainal Arifin, My Daughters Siti
Inelza Ramadhani bt Indra and Siti Febryza bt Indra,
My Sister and Brothers***

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in
fulfilment of the requirement for the degree of Master of Science

**DESIGN OF SINGLE SWITCH RECTIFIER FOR ELECTRIC VEHICLE
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February 2002

Chairman: Associate Professor Norman Mariun, Ph.D., P. Eng.

Faculty: Engineering

A single switch rectifier was developed in this thesis, which has continuous input and output currents. The design and implementation of a single switch three-phase multi resonant rectifier delivering 147 V_{dc} at 2.2 kW output has been carried out. By the use of a multi resonant scheme, the IGBT operates with zero current switching and the diode operates with zero voltage switching.

This multi-resonant rectifier with a single transistor is capable of drawing a higher quality input current waveform, good power factor and low stresses on the semiconductor devices. Buck type converter was used for the power stage, and hence the output voltage is lower than the input voltage. Moreover, these rectifiers have a wide load range with low stress on semiconductor devices. Simulation and experimental results are presented. The total harmonic distortion (THD) of the

line current is less than 5% and the system efficiency is about 90% at 25% of maximum load.

The single switch rectifier using multi resonant zero current switching has been simulated using OrCad release 9.1 software for 25% of maximum load. A good agreement between simulation and experimental results has been achieved.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

**REKABENTUK PENERUS SUIS TUNGGAL UNTUK APLIKASI
PENGECAS BATERI KERETA ELEKRIK**

Oleh

I N D R A N I S J A

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Sebuah penerus suis tunggal telah dibangunkan dalam tesis ini, yang mempunyai arus masukan dan arus keluaran yang terus menerus. Rekabentuk dan pembuatan sebuah penerus suis tunggal menghantarkan voltan keluaran 147 V_{dc} dan kuasa keluaran 2.2 kW telahpun dilaksanakan. Dengan menggunakan sebuah skim berbilang salunan, IGBT beroperasi pada pensuisan arus sifar dan diod beroperasi pada pensuisan voltan sifar.

Penerus berbilang salunan dengan transistor tunggal ini mempunyai kemampuan untuk menghasilkan bentuk gelombang arus yang berkualiti tinggi pada faktor kuasa yang baik dan tekanan yang rendah pada peranti semikonduktor. Penerus jenis lekuk ini digunakan untuk tingkatan tenaga, dan sebab itu voltan keluaran

lebih rendah daripada voltan masukan. Lebih dari itu, penerus ini mempunyai kadar beban yang luas dan tekanan yang rendah pada peranti semikonduktor. Hasil simulasi dan ujikaji dibentangkan pada tesis ini. Herotan harmonik menyeluruh (THD) pada arus fasa ialah kurang daripada 5 peratus dan kecekapan sistem lebih kurang 90 peratus untuk 25 peratus beban maksimum.

Penerus suis tunggal menggunakan berbilang salunan pensuisan arus sifar telah disimulasikan dengan menggunakan perisian OrCad release 9.1 untuk 25 peratus daripada beban maksimum. Perbandingan diantara hasil simulasi dengan hasil ujikaji yang diperolehi menunjukkan persamaan yang hampir diantara satu sama lain.

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I certify that an Examination Committee met on 8th February 2002 to conduct the final examination of Indra Nisja on his Master of Science thesis entitled "Design of Single Switch Rectifier for Vehicles Electric Battery Charger Application" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotation., and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.



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TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGMENTS	vii
APPROVAL SHEETS	viii
DECLARATION FORM	x
TABLE OF CONTENTS	xi
LIST OF TABLES	xiv
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xx

CHAPTER

I	INTRODUCTION	1
	Problems in Electric Vehicle Development	2
	Long Battery-Charging Time	2
	Storage Batteries	3
	The Cost of Battery	4
	Power Quality Problem	5
	Aim and Objectives	6
	Scope of Work	7
II	LITERATURE REVIEW	9
	Power Converter	9
	AC to DC converter	9
	Buck Converter	10
	Boost Converter	10
	Flyback Converter	10
	Converter source classification	11
	Voltage source converter	11
	Current source converter	11
	Improve Input Power Factor and Harmonics	12
	Reduction by PWM Technique	12



Resonant Converter	17
Parallel Resonant Converter	17
Single Switch Three-Phase Zero Current Switching-	
Quasi Resonant Buck Rectifier	19
Series Resonant Converter	21
Improve Input Power Factor and Harmonics Reduction-	
Rectifier Without PWM Technique	23
Reduction of EMI Emission of an On-Board Charger	25
Fast Charging Electric Vehicle Battery	25
Power Factor Correction	31
Power Factor Correction in Switching Power Supplies	32
A Single Stage Power Factor Corrected AC/DC Converter	33
Electric Vehicles Batteries	37
Lead Acid battery	38
Nickel Cadmium Batteries	40
Ovonic Ni-Metal Hydride Batteries	41
III MATERIALS AND METHODS	44
Introduction	44
Buck Converter	45
Power Factor Correction Topology	50
Zero Current Switching	52
Zero Voltage Switching	57
Power Semiconductor in Resonant Converter	58
Insulated Gate Bipolar Transistor (IGBTs)	58
High Power Circuit Controller Design	58
IGBT in Zero Voltage Switching	61
IGBT in Zero Current Switching	61
Insulated Gate Bipolar Transistor (IGBT) Gate Driver	62
Gate Drive Requirements of High-Side Devices	64
IGBT Gate Resistance	65
Turn Off Voltage	66
Normalized Control Characteristic and Stresses	69
Design of Single Transistor Three Phase Multi-	
Resonant ZCS Rectifier	71
Component Design for Multi Resonant Converter	74
Semiconductor	74
Magnetic Core Material	75
Output Inductor Design	75
Operation of the Bootstrap Circuit	82
Factors Affecting the Bootstrap Supply	83
Calculating the Bootstrap Capacitor Value (C_2)	84



	Selecting the Bootstrap Diode (D_{bs})	86
	Snubber Circuit	86
	Battery Chargers Design	88
	Switch mode Lead Acid Battery Charger - Controller (UC3909)	89
	Charging Techniques	90
	Constant Voltage Charging	91
	Pulsed Charging or Discharging Current	92
	Stepped Charging Current	92
	Current Sensor	93
	Differential Output Voltage Sensor	93
	Housekeeping and Battery Temperature Sensing	94
	Charge State Decoder	95
	High Power Modules and Power Switches Multiple Discretes	96
	Equalising Junction Temperatures of Multiple Discretes	98
	Selection of Heat Sink	99
	Conclusion	104
IV	RESULTS AND DISCUSSIONS	107
	Simulation Results	107
	Experimental Results	111
	Charger Characteristic	126
	Total Harmonic Distortion (THD)	127
	Charger Efficiency	129
V	CONCLUSION AND RECOMMENDATION	130
	Conclusions	130
	Recommendations For the Future Work	131
	REFERENCES	133
	APPENDIX	
	A Rectifier and Control Design	137
	B Components Data Sheets	151
	BIODATA OF AUTHOR	174

LIST OF TABLES

Table		Page
Table 1	Characteristic values of different battery modules	42
Table 2	Measured current harmonic at the fundamental component- of the input current 12.2 Ampere	128



LIST OF FIGURES

Figure		Page
2 1	Voltage Source Converter	12
2 2	Current Source Converter	12
2 3	Single Switch Three-Phase Zero Current Switching Quasi-Resonant Buck Rectifier	19
2 4	a Zero Current Switching Quasi Resonant Buck Converter b Phase a Tank Capacitor Voltage, Multi Resonant Zero Current Switching Buck Converter	20
2 5	Schematic of Series Converter	22
2 6	Simplified Schematic of the Power Circuit of the Charger	26
2 7	Rectifier Block Diagram	27
2 8	Fast Charger Block Diagram	29
2 9	Schematic of SEPIC, which in include high frequency EMI filter	34
2 10	Schematic of BIFRED, which in include high frequency EMI filter	35
2 11	Power and Control Circuit of Single Stage Converter	36



2.12	Comparison Results Between Conventional and Power-Factor Correction Rectifier	37
2.13	Specific Energy per Weight	43
2.14	Specific Energy per Volume	43
3.1	Block diagram of propose converter	45
3.2	Buck converter topology	47
3.3	Voltage Transfer Ratios for Buck, Boost and Flyback Converter	49
3.4	Multi resonant zero current switching rectifier	52
3.5	Current and voltage waveforms of hard and resonant switching systems	53
3.6	The single switch multi resonant zero current switching converter waveforms	55
3.7	Full-wave zero-voltage switch - topology and waveforms	57
3.8	Comparison of MOSFET and IGBT	59
3.9	Voltage vs. Current Density	60
3.10	V_{ON} vs. I_C for Different IGBTs	60
3.11	IR 2125 pin configuration	63
3.12	Zener Gate Voltage Clamp	68



3.13	Diode Capacitor Voltage Clamp	69
3.14	Basic Buck Regulator	76
3.15	Output Current Waveform for Buck Regulator with L in-Continuous Mode Operation	77
3.16	Bootstrap Diode and Capacitor circuit used with IR 2125 Control IC's	83
3.17	Snubber circuit for IGBTs	87
3.18	UC 3909 pin configuration	91
3.19	Battery charger control block diagram	97
3.20	Use of Heat Spreader Providing Thermal Coupling Between Discrete	99
3.21	Thermal Power Flow Model for a Static Switch Mounted on a Heat Sink	103
3.22	Switch Current and Voltage Waveforms	104
4.1	Simulation Circuit for Single Switch Rectifier	108
4.2	Pspice Simulation; IGBT Switch Collector to Emitter Blocking Voltage Waveform and IGBT switch Gate Voltage Waveform	109
4.3	Pspice Simulation Result; IGBT Switch Current Waveform and IGBT Gate Voltage Waveform	109
4.4	Pspice Simulation; Blocking Output Voltage Diode (V_{Dd}) waveform	110



4.5	Pspice Simulation; IGBT Switch Current Waveform and IGBT Switch Collector to Emitter Blocking Voltage Waveform	110
4.6	Single Switch Multi Resonant Zero Current Switching Rectifier for Electric Vehicle Battery Charger	112
4.7	Hardware Components	113
4.8	Hardware During Building and Testing	113
4.9	Controller Waveform; (B) Saw Tooth Waveform Timing Capacitor; (D) IC Controller Output Waveform before Connected to the Power Circuit	117
4.10	Controller Waveform; (B) IC Controller Output Waveform, (D) IR2125 Output Waveform Before Connected to the Power Circuit	118
4.11	Controller Output Waveform; (1) IGBT Gate Voltage Waveform and (2) IC Controller Output Waveform After Connected to Feedback Components	119
4.12	Rectifier Waveform for 36V Battery Pack; (1) IGBT Switch Output Voltage and (2) IGBT Gate Voltage, Before Output Side Resonant Components Connected, Using Probe Multiplier 10X	120
4.13	Rectifier Waveform for 36V Battery Pack; (1) IGBT Gate Voltage and (2) Current Waveform of the IGBT Using Probe Multiplier 10X	121
4.14	Rectifier Waveform for 36V Battery Pack; (1) Blocking Voltage Waveform of the Output Diode V_{Dd} and (2) IGBT Gate Voltage Waveform Using Probe Multiplier 10X	122



4.15	Rectifier Waveform for 36V Battery Pack; (A) IGBT Collector to Emitter Voltage Waveform and (B) Output Diode (V_{Dd}) Voltage Waveform Using Probe Multiplier 10X	123
4.16	Rectifier Waveform for 36V Battery Pack; (a) IGBT Collector to Emitter Voltage Waveform and (b) IGBT Gate Voltage Waveform Using Probe Multiplier 10X	124
4.17	Rectifier Waveform for 36V Battery Pack; Output Diode (V_{Dd}) Voltage Waveform with the Peak Voltage 120.6 V	125
4.18	36V, 30 AH Sealed Battery Charge Characteristic	126
4.19	Input Current Harmonic	128
4.20	Efficiency Versus Output Voltage, for 30AH, 36V Battery at 12.2 Ampere Charging Current	129

ABBREVIATIONS

Symbols

A	Ampere/Gain of Voltage Sense Amplifier
AC	Alternating Current (A)
A_c	Area of Center Pole (m^2)
AH	Ampere Hour
A_x	Wire Cross Sectional Area (m^2)
A_w	Total Winding Window Area (m^2)
B_{max}	Maximum Flux Density (Tesla)
BJT	Bipolar Junction Transistor
C	Capacitor (Farad)
C_b	Bypass Capacitor(Farad)
C_{bs}	Bootstrap Capacitor(Farad)
CCM	Continuous Conduction Mode
C_d	Output Side Resonant Tank Capacitor(Farad)
C_f	Capacitor Filter (Farad)
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
C_r	Input Side Resonant Tank Capacitor (Farad)
CSI	Current Source Inverter
D	Diode
D_b	Freewheeling Diode
D_{bs}	Bootstrap Diode

DC	Direct Current
DCM	Discontinuous Conduction Mode
D_d	Output Diode Resonant Component
D_p	Output Protection Diode
EMI	Electro Magnetic Interference
F	Normalized Switching Frequency(Hz)
f	Frequency (Hz)
FB	Full Bridge
Fe_2O_3	Iron Oxide
FEC	Future Electric Concept Vehicle
FET	Field Effect Transistor
f_o	Operating frequency (Hz)
HP	Horse Power
IC	Integrated Circuit
I_c	Collector Current (A)
IEC	International Electrotechnical Commision
ICE	Internal Combustion Engine
$I_{cbs(leak)}$	Bootstrap capacitor leakage current (A)
I_E	Emitter Current (A)
I_f	Fundamental Current (A)
I_g	Peak Input Current (A)
I_{lson}/I_{lsoff}	level shift currents required to switch output on/off (A)
IGBT	Insulated Gate Bipolar Transistor
i_L	Line Current (A)

I_n	n Level of Harmonic Current
I_{out}	Output Current (A)
i_s	IGBT Switch Current (A)
IR	International Rectifier
I_{qbs}	Quiescent VBS Supply Current (A)
J	Junction, or energy density (Joule)
J_g	Normalized peak Input Current
kg	Kilo Gram
kHz	Kilo Herzt
KM	Kilo Meter
kVA	Kilo Volt Ampere
K_u	Winding Packing Factor
L	Inductor (H)
LC	Inductor Capacitor Filter
L_f	Filter Inductor (H)
LISN	Line Impedance Stabilization Network
L_o	Output Inductor (H)
L_r	Resonant Inductor (H)
M	Modulation Index
M_g	Normalized peak Input Voltage
MOSFET	Metal Oxide Silicon Field Effect Transistor
N	Number of Turns
NC	Number of Cells
N_{min}	minimum turns

NiMH	Ovonic-Nickel Metal Hybride
NiCd	Nickel Cadmium
NO	Nitrogen Oxide
p	Number of Pulse
P	Active Power
PCB	Printed Circuit Board
p.f	Power Factor
PFC	Power Factor Correction
Pin	Input Power (W)
PRC	Parallel Resonant Converter
PWM	Pulse Width Modulation
Q	The charge (Coulomb), or IGBT symbol
Q_g	Gate charge of high side FET
R	Resistor (Ohm)
R_{cs}	Current sense resistor (Ohm)
R_{cs}	Thermal Resistance from Junction to Case ($^{\circ}\text{C/W}$)
R_G	Gate Resistor (Ohm)
RMS	Root Mean Square
RP_1	Thermistor Emulation Potentiometer
RTF	Rotating Field Transformer
SO ₂	Sulfur Dioxide
T	Tesla
t	Time (Second)

T_A	Ambient Temperature ($^{\circ}\text{C}$)
THD	Total Harmonic Distortion (%)
T_J	Junction Temperature ($^{\circ}\text{C}$)
t_w	pulse width of level shift currents
U_2	Lead Acid Battery Charger Controller IC
UPS	Uninterruptible Power Supply
V	Voltage
V_b	Base Voltage (V)
V_{Cr}	Resonant Capacitor Voltage (V)
V_{CE}	Collector to Emitter Voltage (V)
V_f	Forward voltage drop across the bootstrap diode (V)
V_{GE}	Gate to Emitter Voltage (V)
V_g	Peak Phase Voltage (V)
V_G	Gate Voltage (V)
V_{in}	Input Voltage (V)
V_L	Line Voltage (V)
V_{LS}	Voltage drop across the low side FET or load(V)
V_{MAX}	Maximum Voltage (V)
V_o	Output Voltage (V)
VSI	Voltage Source Inverter
V_Q	IGBT Voltage (V)
VRLA	Valve Regulated Lead Acid Battery
V_{cra}	Resonant Capacitor Voltage on Phase A
V_{th}	Threshold Voltage(Volt)